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(19) (CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Method for Monitoring Real-Time Hydraulic Fracture Propagation

(72) Abou-Sayed, Ibrahim S. - U.S.A. ;

(73) Same as inventor

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Canada

ABSTRACT

A process for monitoring real-time hydraulic fracture propagation wherein remote microseismic activity is utilized. Selectively placed geophones detect generated longitudinal and shear-waves which give an estimate of direction of the fracturing. Having obtained the direction of the fracture, polarization is used to obtain the fracture source. Subsequently obtained microcracks which define the main fracture boundary are recorded as microseismic events. Microcracking in the formation is sequenced in time thereby allowing the real-time fracture height to be estimated.

METHOD FOR MONITORING REAL-TIME HYDRAULIC FRACTURE PROPAGATION

This invention relates to a method for monitoring real-time hydraulic fracture propogation.

Hydraulic fractures are produced in oil and gas fields, in solution mining operations, in fresh water aquifers, and certain other resource recovery operations for the purpose of extracting more fluid from the earth than is possible in wells that have not been hydraulically fractured. Hydraulic fractures are also used to more effectively disperse liquid waste into subsurface formations when these liquids are pumped into disposal wells. Generally stated, hydraulic fractures increase the hydraulic conductivity of the subsurface geologic formation, permitting greater amounts of fluid to be injected and extracted than would be the case if the fractures were not present.

Experience has shown, and it is now commonly accepted, that most hydraulic fractures are large, planar structures with surface areas from tens to many thousands of square meters. Because of their economic importance in resource recovery and waste disposal, it is often desirable to establish the orientation and, if possible, the dimensions of the fracture plane in the earth. Knowledge of fracture orientation and dimensions permits wells to be drilled in optimal locations to take advantage of the non-uniform drainage or injection patterns that hydraulic fractures produce. In this way it may be possible to extract more of the resources in a field using a smaller number of wells that would be possible if fracture geometry were not known. Fracture orientation can also be used to determine the orientations of the principal stress directions in the earth

around the fracture. Knowledge of stress directions in the earth is important for certain engineering purposes, such as tunneling and blasting, and in the study of regional geologic structures and earthquakes. Furthermore, information about the rate and directions of hydraulic fracture growth can be used in improving the design and production of the fractures, thereby resulting in economic savings to the individuals and organizations who use hydraulic fractures in their operations.

A hydraulic fracture analysis method is disclosed in US-A-4,802,144. Via this method free and forced oscillations in a well were used to determine fracture impedance by well head pressure measurements and hydraulic models. Because impedance is a function of fracture dimensions and the elasticity of the surrounding rock, impedance analysis can be used to evaluate the geometry of the fracture by analyzing the data which results from free and forced oscillations in the well, and looking for a match between the data and theoretical models of projected shapes of the fracture.

An apparatus and method for determining directional characteristics of fracture systems in subterranean earth formations is disclosed in US-A-4,446,433. The apparatus utilized antenna packages from which a transmitting antenna was propelled from a wellbore penetrating the earth formation into the fracture system. An axial and singular three-dimensional location of the fracture or other fracture profiles were readily mapped.

These prior art methods are directed to "static" methods for determining fracture geometry and growth. Therefore, what is needed is a method for monitoring real-time hydraulic fracture propagation or growth.

According to the invention, real time hydraulic fracture propagation is monitored by utilizing microseismic activity resultant from the propagation of a hydraulic fracture. At least three geophones are used to map the evolution of the fracture with time. The geophones are orientated to receive seismic waves from three mutually perpendicular directions, which waves originate from disturbances created by the propagating fracture. A non-random time sequence of the disturbances is used to develop a spatial map of the disturbances caused while the fracture propagates. The geophones are advantageously multi-component geophones.

These disturbances are sensed by the geophones, recorded, and plotted. By plotting the disturbances by depth and time, the fracture height can be measured in real time. A similar plot is made from disturbances obtained as the fracture length extends with time. A third plot is used to measure the azimuth (direction) of each disturbance. A cross plot between fracture height versus fracture length is developed. This gives a contour which represents evolution of the fracture with time.

The plotting of non-random, time sequence of the disturbance is possible because of seismic waves which result from the development of two different kinds of cracks. The first crack is generated under tensile loading conditions. Sounds emanating from microcracks which develop at or close to the main crack are used to record the microseismic disturbances resultant from the propagation of the fracture. These microcracks are primarily shear failures caused by increased pore pressure due to leak off.

Preferably, the microseismic activity or microcracks are detected by placing said geophones in three observation wells located about 60 to 150 feet (18 to 46m) from the well from which the crack is being propagated.

Reference is now made to the accompanying drawings, in which :

Fig. 1 depicts the estimated microseismic source depths plotted as circled points at the time of source activation:

Fig. 2 is graphical representation which shows a fracture turning with time;

Fig. 3 illustrates schematically an areal/spatial view of the evolution of a fracture with time; and

Fig. 4 depicts schematically possible boundaries of a fracture resultant from leak-off and micro cracks.

In the practice of this invention a well is drilled from which it is desired to hydraulically fracture a formation. A method for hydraulically fracturing a formation is disclosed in US-A-4,067,389. Once the well for creating the hydraulic fracture has been completed, three other wells are drilled. These wells are placed at a location adjacent to the well in which hydraulic fracturing will be conducted. They are located at a distance sufficient from the well in which hydraulic fracturing will be conducted so as to enable a geophone or an array of geophones positioned in said wells to detect sounds emanating from the formation as it cracks.

Three-component geophones are utilized. As such, the geophones have the capability of detecting compressional waves, vertical shear waves, and horizontal shear waves. Geophones which can be used for this purpose are discussed in US-A-4,280,200. The geophones are positioned in each of the wells adjacent to the well in which hydraulic fracturing is

conducted so as to detect sounds coming from micro-cracks in the formation subsequent to the main crack being generated. These geophones are located at a depth in the sound receptor well at which it is anticipated that the fracture will form. Sounds received on the geophones are recorded on a continuous recording device which device is known to those skilled in the art. By using these geophones the direction and dimensions of the fracture can be determined. Geophones are also discussed in US-A-4,403,312 and US-A-4,899,321.

The geophones are oriented to receive waves emanating from the generated fracture. They are oriented in three mutually perpendicular directions. By utilizing the polarization (directionality of the signal) the azimuth of the disturbance (source) can be estimated in relation to the geophone. By recording the p-wave (longitudinal wave) and the s-waves (shear length waves), the range (distance) of the source can be estimated.

Once the geophones and continuous recording equipment are functioning, hydraulic fracturing is conducted in the well. As hydraulic fracturing is conducted, two kinds of cracks develop. The first is called the main crack which is generated under tensile loading conditions. The second to develop are the microcracks. These develop at or close to the main crack boundary and are the source of the recorded microseismic events. These microcracks are primarily shear failures caused by increased pore pressure due to fluid leakoff into the formation. As the effective stresses on the rock mass change, the conditions for shear failure (Mohr-Coulomb failure envelope) are satisfied, thereby creating cracks. Microcracking is more easily accomplished in tight rocks with leakoff and may approach the extreme outer boundary of the main crack.

As the hydraulic fracture propagates through the formation the microseismic sources or sounds emanating from the microcracks are activated randomly in time and randomly on a finite plane which approximates the fracture surface. When the plane is vertical, the upper limit of the microcrack source as relates to the depth at any given time approximates the fracture height reached at that time. This is shown in Figure 1, which represents the plot of the microseismic or microcracking source depths as a function of time. In this figure, the estimated microseismic or microcrack source depths 22 are plotted at circle points at the time of source activation. The source activation time is referenced to the start time of the treatment. The upper time limit of the microseismic source or microcracked depth is shown as the solid line 20 in Figure 1. As is shown in Figure 1, during the first ten minutes of the hydraulic fracture treatment the fracture height grows to within about 25 percent of its final maximum value. It is then followed by a period of slow growth to a maximum height of about 400 feet (122m). During the final 30 minutes or so of the hydraulic fracture treatment, the fracture height appears to decline, reaching the value of about 100 (30m) to about 300 feet (91m) by the end of the fracture treatment. As is shown in Figure 1, a good correlation exists between the fracture height estimated from pressure data shown as broken line 18 and that estimated from microseismic or microcrack data. By plotting the microseismic events, i.e., depth versus time, the fracture height can be measured as it changes in real time.

Similar plots can be generated for fracture length versus time as the fracture develops. A third such plot can be used to monitor the azimuth of each event. This plot comprises a three dimensional plot. The first two dimensions are spatial (x-y space plane) which represents the surface of the earth. The

CLAIMS:

1. A method for monitoring real time hydraulic fracture propagation comprising:

a) determining the direction in which a hydraulic fracture will propagate from a wellbore;

b) placing at least three geophones in the area wherein it has been determined that the fracture will propagate which geophones are oriented to receive sonic waves from three mutually perpendicular directions;

c) initiating a hydraulic fracture via said wellbore which fracture proceeds into the formation and creates a maincrack and microcracks;

d) using a non-random time sequence of the microcrack sounds as obtained from the geophone to develop a spatial map of the microcracks by sounds therefrom which identify the polarization and direction of said microcracks.

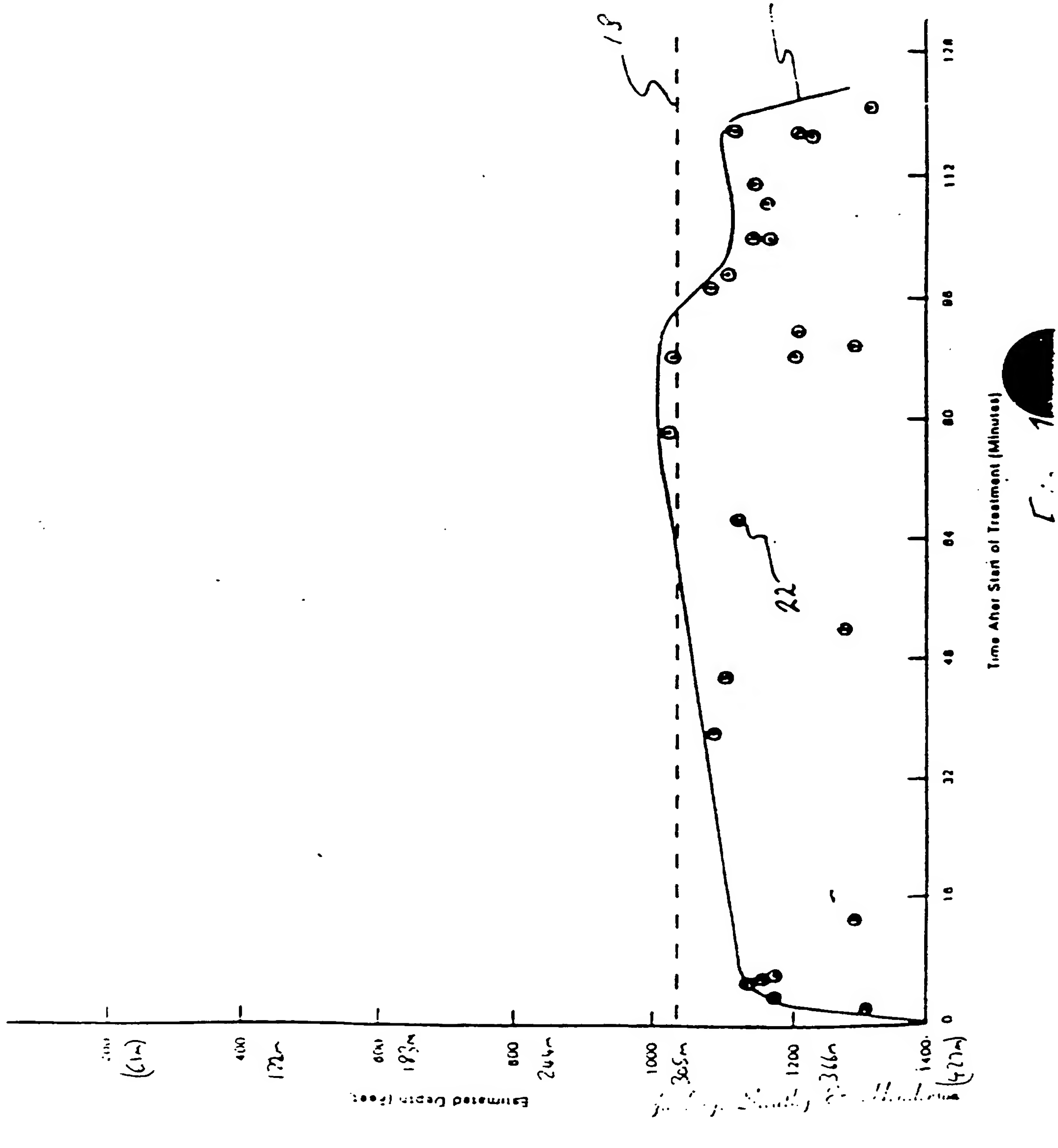
2. A method according to claim 1 wherein the microseismic activity or microcracks are detected by placing said geophones in three observation wells located about 60 to 150 feet (18 to 46m) from the well from which the fracture is being propagated.

3. A method according to claim 1 or 2 wherein the microseismic source or microcrack sound are plotted as a function of time.

third is time. If only a two dimensional plot is generated, then changes in fracture direction can be monitored as shown in Figure 2. As is shown in Figure 2 the turning of a fracture can also be monitored with time.

As is shown in Figure 3, when a cross-plot between fracture height versus fracture length is developed, then contours representing evaluation of a fracture with time can be generated. Of importance here is the non-random, time sequence of the generated events/waves from hydraulic fracturing in wellbore 10.

Figure 4 also shows the possible boundary of the crack/leak-off 12 and microcrack 16. As is shown in Figure 4, possible microcracking is accomplished when stress conditions are suitable for Mohr Coulomb failure criterion to hold. The outer crack boundaries 14 are also shown in Figure 4 as well as a leak-off boundary 12. Cracks are generated from hydraulic fracturing conducted in wellbore 10. Based on the above occurrences, microcracking in space is sequenced in time (non-random) with the outermost place of microcracking taking place at a later time.


Time After Start of Treatment (Minutes)
0
16
32
48
64
80
96
112
128
Estimated Depth (Feet)
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600
800
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(427m)
18
20
22

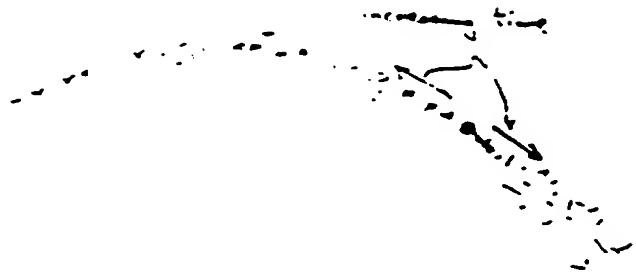

Fig. 2

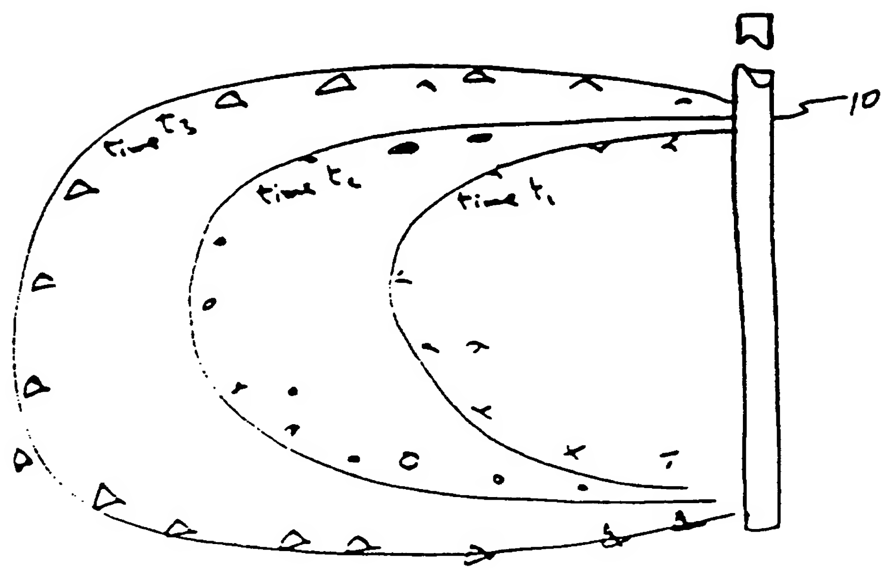

Fig. 3

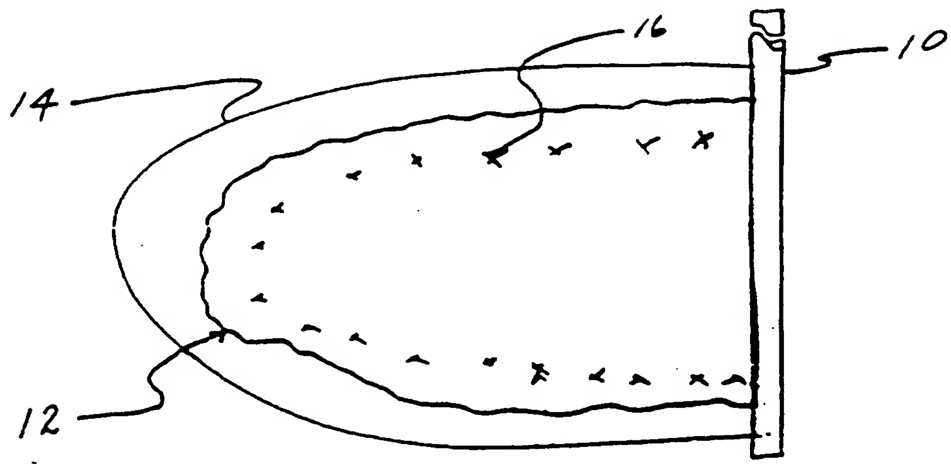

Fig. 4